NASA/TM—2000–209891, Vol. 87

Te[illegible] Report S[illegible] on the
B[illegible]osystem-A[illegible]sphere Study (BOREAS)

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[illegible]S Level-1B MAS Imagery:
[illegible] Relative X and Y Coordinates

[illegible] *Hubanks, J.A. Newcomer, and S. Ungar*

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[illegible]ce Flight Center
[illegible]ryland 20771

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NASA/TM—2000–209891, Vol. 87

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall, Editor

Volume 87

BOREAS BOREAS Level-1B MAS Imagery: At-sensor Radiance, Relative X and Y Coordinates

Richard Strub, Raytheon ITSS
Paul Hubanks, RDC
Jeffrey A. Newcomer, Raytheon ITSS
Stephen Ungar, NASA Goddard Space Flight Center, Greenbelt, Maryland

National Aeronautics and
Space Administration

Goddard Space Flight Center
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BOREAS Level-1b MAS Imagery: At-sensor Radiance, Relative X and Y Coordinates

Richard Strub, Paul Hubanks Jeffrey A. Newcomer, Stephen G. Ungar

Summary

For BOREAS, the MAS images, along with the other remotely sensed data, were collected to provide spatially extensive information over the primary study areas. This information includes detailed land cover and biophysical parameter maps such as fPAR and LAI. Collection of the MAS images occurred over the study areas during the 1994 field campaigns. The level-1b MAS data cover the dates of 21-Jul-1994, 24-Jul-1994, 04-Aug-1994, and 08-Aug-1994. The data are not geographically/geometrically corrected; however, files of relative X and Y coordinates for each image pixel were derived by using the C-130 INS data in a MAS scan model. The data are provided in binary image format files.

Note that the level-1b MAS data are not contained on the BOREAS CD-ROM set. An inventory listing file is supplied on the CD-ROM to inform users of the data that were collected. See Section 15 for information about how to acquire actual level-1b MAS images.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-1b MAS Imagery: At-sensor Radiance, Relative X and Y Coordinates

1.2 Data Set Introduction

The BOReal Ecosystem-Atmosphere Study (BOREAS) Staff Science effort covered those activities that were BOREAS community level activities or required uniform data collection procedures across sites and time. These activities included the acquisition of the relevant aircraft image data. Data from the Moderate Resolution Imaging Spectroradiometer (MODIS) Airborne Simulator (MAS) onboard the National Aeronautics and Space Administration (NASA) C-130 aircraft were acquired by staff of the

Medium Altitude Aircraft Branch at NASA Ames Research Center (ARC) and provided for use by BOREAS researchers.

BOREAS Information System (BORIS) personnel worked with MAS personnel at NASA Goddard Space Flight Center (GSFC) in processing the MAS and related C-130 navigation data to derive and archive the 12-band level-1b MAS imagery.

1.3 Objective/Purpose

For BOREAS, the MAS data, along with the other remotely sensed images, were collected in order to provide spatially extensive information over the primary study areas. This information includes detailed land cover and biophysical parameter maps such as fraction of Photosynthetically Active Radiation (fPAR), and Leaf Area Index (LAI). The MAS data were also to serve as test data sets for the MODIS Land Group (MODLAND) in exercising its parameter derivation algorithms.

1.4 Summary of Parameters

Level-1b MAS data in the BORIS contain the following parameters:

Descriptive information as American Standard Code for Information Interchange (ASCII) text records, at-sensor radiance values for image bands 1 to 12, relative X and Y pixel coordinates, and per pixel view zenith and azimuth angles.

1.5 Discussion

BORIS staff created the level-1b MAS imagery by: 1) extracting aircraft location and attitude information from BOREAS level-0 C-130 navigation data, 2) combining MAS image and C-130 navigation data to make a Hierarchical Data Format (HDF) file, 3) extracting image and ancillary information from the HDF file and reformatting it into a band sequential (BSQ) format 8-mm tape product for distribution, and 4) creating a descriptive inventory of the MAS data product in the BORIS data base.

1.6 Related Data Sets

BORIS Level-2 MAS Surface Reflectance and Temperature Images in BSQ Format
BOREAS RSS-02 Level-1b ASAS Image Data: At-sensor Radiance in BSQ Format
BOREAS Level-2 NS001 TMS Images: Reflectance and Temperatures in BSQ Format
BOREAS Level-1b TIMS Imagery: At Sensor Radiance in BSQ Format
BOREAS Level-3a Landsat TM Imagery: Scaled At-sensor Radiance in BSQ Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

BOREAS Staff Science

2.2 Title of Investigation

BOREAS Staff Science Aircraft Data Acquisition Program

2.3 Contact Information

Contact 1:

Stephen G. Ungar
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-4007
(301) 286-0239 (fax)
ungar@highwire.gsfc.nasa.gov

Contact 2:
Jeffrey A. Newcomer
Raytheon ITSS
Code 923
NASA GSFC
Greenbelt, MD 20771
(301) 286-7858
(301) 286-0239 (fax)
Jeffrey.Newcomer@gsfc.nasa.gov

3. Theory of Measurements

MODIS was developed as part of the Earth Observing System (EOS) to meet the scientific needs for global remote sensing of clouds, aerosols, water vapor, land, and ocean properties from space. MODIS is scheduled to be launched in 1998 on the EOS AM-1 platform (King et al., 1995). In support of MODIS remote sensing algorithm development, the MAS was developed by Daedalus Enterprises, Inc., for NASA's high-altitude ER-2 research aircraft, and is an outgrowth of the development of the Wildfire infrared imaging spectrometer. In a cooperative effort between the High Altitude Missions Branch at NASA ARC and the MODIS science team, Wildfire was converted to the MAS and upgraded over a series of several experiments, starting with the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment cirrus campaign (FIRE II) in November 1991.

The locations of the MAS spectral channels were chosen to enable a wide variety of earth science applications. Of the 50 MAS channels, 19 have corresponding channels on MODIS. The remaining MAS channels fill in the spectral region around MODIS locations and some provide unique coverage.

One application of the MAS solar channels is the study of cloud properties at high spatial resolution. The majority of the molecular absorption in the shortwave region of the solar spectrum is due to water vapor, with some ozone absorption in the broad Chappuis band (~0.6 µm) continuum. The reflectance measurements in the 1.61, 2.13, and 3.74 µm windows provide useful information on the cloud droplet size. Reflectance measurements in the visible wavelength region, in contrast, show little variation with droplet size and can thus be used to retrieve cloud optical thickness (cf. Twomey and Cocks, 1982; Nakajima and King, 1990). The reflectance at 0.94 µm is attenuated by atmospheric water vapor; these measurements, in conjunction with spectrally close atmospheric window reflectances, can provide an estimate of the total precipitable water in cloud-free regions (Kaufman and Gao, 1992).

Cloud properties can also be estimated from the thermal bands. In the 3.7-µm window, both solar reflected and thermal emitted radiation are significant, though the use of the reflectance for cloud droplet size retrieval is seen to be much more sensitive than the thermal component. CO_2 absorption is important around 4.3 µm and at wavelengths greater than about 13 µm. The MAS bands in these spectral regions can indicate vertical changes of temperature. The 4.82- to 5.28-µm channels are useful for investigating both horizontal and vertical distributions of moisture. Low-level moisture information is available in the split window measurements at 11.02 and 11.96 µm, and correction for moisture attenuation in the infrared windows at 3.90, 11.02, and 11.96 µm enables estimation of sea surface skin temperature (Smith et al., 1995).

The MAS infrared spectral bands enable the study of cloud properties at high spatial resolution. Products include cloud thermodynamic phase (ice vs. water, clouds vs. snow), cloud top properties, and cloud fraction. The cloud top properties (height, temperature, and effective emissivity) can be investigated using the CO_2 slicing algorithm (Wylie et al., 1994) that corrects for cloud semitransparency with the MAS infrared CO_2 bands at 11.02, 13.23, and 13.72 µm. Cloud phase can be obtained using MAS 8.60-, 11.02-, and 11.96-µm brightness temperature differencing (Strabala et al., 1994) as well as by using visible reflection function techniques (King et al., 1992) utilizing ratios of the MAS 1.61- and 0.66-µm bands.

In addition to the remote sensing of cloud radiative and microphysical properties, the MAS is of value for the remote sensing of land and water properties under channel clear-sky conditions. MAS visible and near-infrared channels have been used to estimate suspended sediment concentration in near-shore waters and to identify water types (Moeller et al., 1993; Huh et al., 1995). Land vegetation properties can also be studied.

In a cooperative effort between Dr. M. King (Code 900, NASA GSFC), BOREAS scientists, and the NASA ARC C-130 missions staff, the MAS was installed into the NASA C-130 aircraft for use during the 1994 summer field campaign of BOREAS.

4. Equipment

4.1 Sensor/Instrument Description

In support of MODIS remote sensing algorithm development, the MAS was developed by Daedalus Enterprises, Inc., for NASA's high-altitude ER-2 research aircraft. Over the past several years, upgrades included new detector arrays, grating modifications, an improved broadband lens for the infrared channels, new Dewars, and various electronics improvements, all of which resulted in improved in-flight radiometric performance.

The overall goal was to modify the spectral coverage and gains of the MAS in order to emulate as many of the MODIS spectral channels as possible. With its much higher spatial resolution (50 m vs. 250-1000 m for MODIS), the MAS is able to provide unique information on the small-scale distribution of various geophysical parameters. Originally and for the BOREAS deployment, the MAS used a 12-channel, 8-bit data system that somewhat constrained the full benefit of having a 50-channel scanning spectrometer. Beginning in January 1995, a 50-channel, 16-bit digitizer was used, which greatly enhanced the capability of the MAS to simulate MODIS data over a wide range of environmental conditions. The 12 data channels configured for the BOREAS Intensive Field Campaign (IFC)-2 C-130 flights were:

Data Channel	MAS Spectral Channel	Center Wavelength (μm)	Spectral Feature
01	01	0.547	green peak
02	02	0.664	chlorophyll
03	04	0.745	NIR plateau
04	05	0.786	NIR plateau
05	06	0.834	NIR plateau
06	07	0.875	aerosols
07	09	0.945	water vapor
08	10	1.623	pollutants
09	20	2.142	mid-IR water
10	32	3.900	
11	45	11.002	surface temperature
12	46	12.032	surface temperature

A total of 716 Earth-viewing pixels are acquired per scan at a scan rate of 6.25 Hz. Information provided by the aircraft inertial navigation system is used to adjust the timing of the digitizer, providing up to 3.5 degrees of roll compensation, in 0.03 degree increments.

4.1.1 Collection Environment

As part of the BOREAS Staff Science data collection effort, the ARC Medium Altitude Aircraft Branch collected the 12-band MAS multispectral scanner data. The MAS was flown on NASA's C-130 aircraft during BOREAS (see the BOREAS Experiment Plan for flight pattern details and objectives). The MAS was flown at medium altitudes aboard NASA's C-130 aircraft based at the NASA ARC and provided 20-meter spatial resolution at nadir at an altitude of 7,500 meters.

4.1.2 Source/Platform

For the BOREAS missions in 1994, the MAS was mounted in the NASA C-130 aircraft operated by the NASA ARC.

4.1.3 Source/Platform Mission Objectives

The C-130 mission objectives for BOREAS were to acquire high-resolution digital imagery with a variety of sensors during optimally clear days of the BOREAS field effort in 1994.

4.1.4 Key Variables

Emitted radiation, reflected radiation, and temperature.

4.1.5 Principles of Operation

The optical system of the MAS is composed of a configuration of dichroic beam splitters, collimating mirrors, folding mirrors, diffraction gratings, filters, lenses, and detector arrays. Both the spectrometer and fore optics portions are mounted to an aluminum optical baseplate assembly, which are pinned and mated.

A full face scan mirror canted 45 degrees to the along track direction directs light into an afocal Gregorian telescope followed by a fold mirror that directs light back through a field stop aperture. A 2.5-cm Pfund assembly paraboloid forms a collimated image of the aperture, which strikes a fold mirror that directs the incoming radiation upward into the aft optics spectrometer unit Thermal and dark visible references are viewed on the backscan rotation of the scan mirror. The thermal reference sources are two blackened copper plate temperature-controllable blackbodies. One blackbody is viewed prior to the Earth-viewing (active scan) portion of the scan, while the other is viewed following the active scan. The telescope alignment is maintained under the low temperature environment using Invar steel and aluminum structural components.

The spectrally broadband energy transmitted and reflected by the dichroics is dispersed onto the detector arrays from blazed diffraction gratings. The bandpass of a channel is determined by the geometry of the detector monolithic array and its location with respect to the grating.

The radiation transmitted by the first dichroic (D1) is reflected by a mirror and diffracted by grating G1 onto a filter and lens assembly that focuses the radiation onto a silicon photovoltaic array with channel response in the wavelength range from 0.55 to 0.95 µm (channels 1-9). Part of the radiation reflected by D1 reflects off the second dichroic (D2) and is redirected by two fold mirrors, diffracted by grating G2, passed through a cold blocking filter, and focused onto an indium-antimonide (InSb) focal plane array assembly containing channels 10-25 (1.61 to 2.38 µm). From D2 the remainder of the spectrally separated energy strikes the third dichroic D3, part of which is reflected and enters port 3, where it is redirected by two fold mirrors, diffracted by grating G3, and focused onto another InSb detector array that defines band-pass characteristics for channels 26-41 (2.96 to 5.28 µm). The remainder of the energy from the scanner is transmitted through dichroic D3 into port 4, where it encounters a fold mirror, diffraction grating G4, and lens that focuses the thermal radiation onto three separate mercury-cadmium-telluride (HgCdTe) detector arrays, each with its own cold-filter to improve the signal-to-noise ratio in its respective wavelength range. Port 4 senses radiation in the wavelength range from 8.60 to 14.17 µm (channels 42-50). The InSb and HgCdTe detectors are cryogenically cooled by liquid nitrogen to 77 K in pressurized Dewars.

4.1.6 Sensor/Instrument Measurement Geometry

BOREAS IFC-2 MAS Instrument/Platform Specifications

```
Platform:                   NASA ARC C-130
Altitude:                   8,000 meters (nominal)
Ground Speed:               200 knots
Pixel Spatial Resolution:   20 meters (at 8,000 meters altitude)
Pixels per Scan Line:       716 (roll corrected)
Scan Rate:                  6.25 scans/second
Swath width:                ~14 km at 7.5 km altitude
```

Total Field of View:	85.92 degrees
Instantaneous Field of View:	2.5 milliradians
Roll Correction:	Plus or minus 3.5 degrees (approx.)
Bits per Channel:	12
Data Rate:	246 Megabytes/hour
Visible Calibration:	Integrating sphere on the ground
Infrared Calibration:	Two onboard temperature controlled blackbodies

4.1.7 Manufacturer of Sensor/Instrument

Daedalus Enterprises, Inc.

4.2 Calibration

Radiometric calibration of the shortwave (<2.5 mm) channels is obtained by observing laboratory standard integrating sphere sources on the ground before and after flight missions, while calibration of the infrared channels is performed in flight by viewing two onboard blackbody sources once every scan. The blackbody sources are located on either side of the scan aperture in the scanner subassembly.

Shortwave Calibration

Two radiometric sources are used for shortwave laboratory calibration during MAS development, a 76.2-cm-diameter integrating sphere maintained at NASA ARC, and a 121.9-cm-diameter integrating hemisphere maintained at NASA GSFC. Both sources are coated with BaSO4 paint and internally illuminated by 12 quartz-halogen lamps. The 76.2-cm sphere is used at ARC for MAS calibrations just prior to the aircraft departure for field deployments as well as immediately following its return. This source is used to monitor long-term stability of the absolute calibration of the MAS. The 121.9-cm hemisphere has often been shipped to deployment sites and employed for MAS calibrations during the deployment. More recently, a 50.8-cm diameter integrating hemisphere was purchased by NASA ARC to ship with the MAS on all deployments. The 50.8-cm integrating hemisphere is coated with Duraflect by Labsphere, North Sutton, NH, and is internally illuminated by 10 lamps. Recent intercomparisons in the 76.2- and 121.9-cm integrating sources suggest that this smaller, more portable, source is suitable for MAS field calibration purposes. This source is set up beneath the MAS prior to each flight to monitor day-to-day fluctuations in the MAS shortwave calibration. Calibration of the spherical integrating sources, both at ARC and during field deployments, is performed by NASA GSFC personnel using a monochromator to transfer calibration to the integrating sources at spectral intervals of 10 nm.

Thus, for each MAS short-wave channel, the radiance is related to digital count by

$$Ib = Sb\,(Cb - Ob) / mb$$

where: Ib is the radiance measured in each short-wave spectral band b
Cb is the count value representing the detector response to the integrating source
Sb is the slope
Ob is the offset (digital counts when observing 'zero' radiance level)
mb is the reflectance of the 458 mirror (not used since 1993)

Details of the short-wave calibration and temperature correction procedure are given by Arnold et al. (1994a, b).

Longwave Calibration

The calibration of wavelengths greater than 2.96 mm is obtained from in-flight observations of two onboard blackbody sources, one operated at the ambient temperature and the other at an elevated temperature (typically 30 °C). The two blackbodies are coated with Krylon interior/exterior ultra flat

black paint. The calibration slope and intercept for the thermal channels are determined from this two point measurement. The blackbody sources are viewed during every scan of the mirror. The amount of energy received by the detector is related to the digitized count value by:

$$I_b = S_b * C_b + i_b$$

where: I_b is the radiance measured in each infrared spectral band b
C_b is the count value representing the detector voltage response to the scene radiance
S_b is the slope
i_b is the intercept

We assume a linear response, as laboratory determinations indicate fractional nonlinearity parameters of less than 0.0001. The slope and intercept, and hence the calibration of counts to radiance, are calculated for each scan line using the count values recorded when viewing two on-board blackbody sources. Using:

w to indicate the warm blackbody,
a to indicate the ambient blackbody,
m to indicate the MAS instrument,

and taking into account blackbody emissivity e, then

$$S_b = e_b (I_{wb} - I_{ab}) / (C_{wb} - C_{ab})$$
$$i_b = I_{ab} + (I_m - I_{ab}) (1 - e_b) - S_b * C_{ab}$$

Blackbody count values are derived as the average of 12 FOVs across each blackbody surface during each scan, with the temperature of the blackbodies monitored by embedded thermistors. The emissivity of the blackbodies was obtained by viewing a well-characterized source in the laboratory, from which the emissivity was determined to be 0.94 and 0.98 for the longwave and shortwave infrared bands, respectively. For typical ocean scene temperatures, corrections for instrument radiation (IM) reflected by the MAS blackbodies are approximately 1.25°C for the longwave and 0.25° C for the shortwave bands, respectively.

Equivalent Planck radiances from the blackbodies are calculated for each spectral band using a spectral response weighted integral of the form

$$I_b (T) = \text{Integral}[B(h, T) F (h)dh] / \text{Integral}[F(h) dh]$$

where: B(h, T) is the Planck function
F(h) is the spectral response for a given band
h is wavelength
T is the blackbody temperature

This can be fitted to an adjusted Planck function for the range of Earth emitted temperatures by introducing coefficients a0 and a1 such that

$$I_b (T) = B(h_b , a1*T + a0),$$

where h_b is the central wavelength or wavenumber of band b.

4.2.1 Specifications

The following table shows the spectral and radiometric characteristics of each MAS channel in the complete 50-channel system. Spectral resolution, defined as the full-width at half-maximum bandwidth of the channel, ranges from around 40 nm in the visible and infrared to about 450 nm in the thermal infrared.

MAS channel	MODIS channel	Central Wavelength (μm)	Spectral Res. (μm)	Equiv Noise*	Scene Temp (K)**	Saturation Level +	Signal-to noise ratio**
1	4	0.547	0.044	0.335		867	45.2 - 1052
2	1	0.657	0.053	0.157		1035	44.6 - 1948
3		0.704	0.042	0.178		1323.	28.7 - 1586
4	15	0.745	0.041	0.180		1412	21.5 - 1406
5		0.786	0.041	0.254		1638	12.4 - 912
6		0.827	0.042	0.237		1890	10.7 - 923
7	2	0.869	0.042	0.281		1935	8.1 - 728
8	7	0.909	0.033	0.150		314	14.9 - 1232
9	19	0.947	0.046	0.226		1600	5.5 - 720
10	6	1.609	0.052	0.039		892	4.5 - 397
11		1.663	0.052	0.029		272	5.8 - 570
12		1.723	0.050	0.026		252	5.1 - 659
13		1.775	0.049	0.026		244	2.8 - 624
14		1.825	0.046	0.025		246	1.3 - 503
15		1.879	0.045	0.029		232	1.1 - 289
16		1.932	0.045	0.014		58	1.4 - 257
17		1.979	0.048	0.019		193	1.7 - 93
18		2.030	0.048	0.022		195	2.0 - 88
19		2.080	0.047	0.012		53	3.8 - 221
20	7	2.129	0.047	0.003		55	1.0 - 1309
21		2.178	0.047	0.023		211	2.3 - 255
22		2.227	0.047	0.026		240	2.0 - 245
23		2.276	0.046	0.027		263	1.6 - 198
24		2.327	0.047	0.026		268	1.5 - 140
25		2.375	0.047	0.033		329	1.0 - 83
26		2.960	0.160	9.780	291	TBD	1.7
27		3.110	0.160	7.050	284	TBD	2.4
28		3.280	0.160	3.090	284	TBD	5.9
29		3.420	0.170	1.280	291	TBD	15.7
30		3.590	0.160	0.720	293	TBD	29.7
31	20	3.740	0.150	0.470	293	TBD	47.5
32	21	3.900	0.170	0.370	292	TBD	62.4
33	23	4.050	0.160	0.300	289	TBD	78.2
34		4.210	0.160	0.810	257	TBD	23.8
35		4.360	0.150	1.740	234	TBD	9.5
36	25	4.520	0.160	0.280	272	TBD	83.2
37		4.670	0.160	0.140	289	TBD	192.9
38		4.820	0.160	0.130	286	TBD	210.2
39		4.970	0.150	0.120	286	TBD	234.9
40		5.120	0.160	0.140	280	TBD	199.7
41		5.280	0.160	0.180	275	TBD	153.7
42	29	8.600	0.440	0.140	292	TBD	363.2
43	30	9.790	0.620	0.120	287	TBD	465.0
44		10.55	0.490	0.090	294	TBD	697.7
45	31	11.02	0.540	0.100	294	TBD	654.7
46	32	11.96	0.450	0.190	294	TBD	370.9
47		12.88	0.460	0.460	291	TBD	161.2
48	33	13.23	0.470	0.490	283	TBD	147.0
49	35	13.72	0.600	1.320	256	TBD	46.7
50	36	14.17	0.420	2.000	229	TBD	25.5

* Noise equivalent DI ($W/m^2/mm/sr$) for channels 1-25; noise equivalent temperature difference NEDT (K) for channels 26-50. All noise measurements are based on in-flight measurements over the Gulf of Mexico on 16 January 1995.

** The thermal data (channels 26-50) are based on in-flight measurements over the Gulf of Mexico on 16 January 1995. The short-wave data (channels 1-25) are based on in-flight measurements over the Gulf of Mexico for the clear-sky scene (low signal level, where the reflectance is often less than 1%) and clouds on the north slope of Alaska on 7 June 1995 for the cloudy scene (high signal level). The range of signal-to-noise values for the short-wave channels reflects this range of scene radiance values.

+ Units of Watts/($meter^2$ * steradian * micrometer)

The wavelength range (in micrometers) of the MAS bands selected for the BOREAS/IFC-2 are:

DATA CHANNEL	MAS BAND	Central Wavelength	50% Bandwidth
01	01	0.547	0.043
02	02	0.664	0.055
03	04	0.745	0.040
04	05	0.786	0.040
05	06	0.834	0.042
06	07	0.875	0.041
07	09	0.945	0.043
08	10	1.623	0.057
09	20	2.142	0.047
10	32	3.900	0.150
11	45	11.002	0.448
12	46	12.032	0.447

4.2.1.1 Tolerance

Details of the shortwave calibration and temperature correction procedure are given by Arnold et al. (1994a, b).

4.2.2 Frequency of Calibration

A single set of calibration coefficients was used for all of the BOREAS flights.

4.2.3 Other Calibration Information

For a more detailed calibration description, the reader is directed to King, et al., 1995.

5. Data Acquisition Methods

As part of the BOREAS Staff Science data collection effort, the NASA ARC personnel collected and provided the 12-band MAS data to BOREAS for use in science investigations. The MAS was flown on NASA's C-130 aircraft during BOREAS (see the BOREAS Experiment Plan for flight pattern details and objectives). Maintenance and operation of the instrument are the responsibility of NASA ARC.

6. Observations

6.1 Data Notes

Flight summary reports and verbal records on video tapes are available for the BOREAS MAS data.

6.2 Field Notes

See the C-130 Flight Summary Report from the Aircraft Data Facility, NASA ARC.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

Each of the MAS flight lines cover a portion of the BOREAS Southern Study Area (SSA) or Northern Study Area (NSA).

The North American Datum of 1983 (NAD83) corner coordinates of the SSA are:

	Latitude	Longitude
Northwest	54.321 N	106.228 W
Northeast	54.225 N	104.237 W
Southwest	53.515 N	106.321 W
Southeast	53.420 N	104.368 W

The NAD83 corner coordinates of the NSA are:

	Latitude	Longitude
Northwest	56.249 N	98.825 W
Northeast	56.083 N	97.234 W
Southwest	55.542 N	99.045 W
Southeast	55.379 N	97.489 W

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

At the nominal C-130 operating altitude of 8,000 m, the MAS provided pixel resolutions of 20 m at nadir to 30 m at the scanning extremes.

7.1.4 Projection

The flight lines are stored in their raw spatial form with pixel resolutions varying from 20 m at nadir to 30 m at the scanning extremes. The provided files of relative X and Y coordinate indicate the relative positions of the pixels from the arbitrary origin. These relative X and Y coordinates were derived from the C-130 navigation data (see Section 9.3).

7.1.5 Grid Description

The provided files of relative X and Y coordinate indicate the relative positions of the pixels. These relative X and Y coordinates were derived from the C-130 navigation data (see Section 9.3).

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Overall the flight lines cover the period of 21-Jul-1994 to 08-Aug-1994.

7.2.2 Temporal Coverage Map

Site	Date	Start Time	End Time	Number of Flight Lines
NSA	08-AUG-1994	14:31:58	15:43:08	7
SSA	21-JUL-1994	15:46:07	17:35:35	10
NSA-YJP	04-AUG-1994	16:47:17	17:23:00	3
NSA-OBS	04-AUG-1994	16:23:44	16:18:02	3
SSA-9YA	24-JUL-1994	17:09:44	17-38:34	3
SSA-FEN	21-JUL-1994	30:35:48	21:15:30	3
	24-JUL-1994	15:58:03	16:28:30	3
SSA-OJP	21-JUL-1994	19:24:26	19:53:21	3
SSA-OBS	21-JUL-1994	18:46:32	19:16:16	3
SSA-90A	21-JUL-1994	17:46:19	18:22:03	3
SSA-YJP	21-JUL-1994	20:00:06	20:26:54	3

7.2.3 Temporal Resolution

The entire NSA and SSA were only imaged once in 1994. The dates and times for individual tower sites are shown in section 7.2.2.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The main parameters contained in the image data files are:

```
Scaled At-sensor radiance
Relative X coordinate
Relative Y coordinate
Scaled View zenith
Scaled View Azimuth
```

The parameters contained in the inventory listing file on the CD-ROM are:

```
         Column Name
------------------------------
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM
INSTRUMENT
NUM_BANDS
PLATFORM_ALTITUDE
MIN_SOLAR_ZEN_ANG
MAX_SOLAR_ZEN_ANG
MIN_SOLAR_AZ_ANG
MAX_SOLAR_AZ_ANG
C130_MISSION_ID
C130_LINE_NUM
C130_RUN_NUM
```

```
C130_SITE
BAND_QUALITY
CLOUD_COVER
MAS_SCAN_SPEED
NW_LATITUDE
NW_LONGITUDE
NE_LATITUDE
NE_LONGITUDE
SW_LATITUDE
SW_LONGITUDE
SE_LATITUDE
SE_LONGITUDE
CRTFCN_CODE
```

7.3.2 Variable Description/Definition

For the image data files:

Scaled At-sensor Radiance

The derived radiant energy incident on the sensor aperture at the time of data collection in the specific MAS wavelength regions.

Relative X Coordinate

The X coordinate of the center of the image pixel in relation to the arbitrarily selected origin. The trend of the X coordinates of the pixels is dependent on the direction of flight of the aircraft. The X, Y coordinate system, starts with the nadir pixel location of image line 1 for all flight lines positioned near the origin (0,0) and progresses based on the direction of flight. The flight direction refers to the angle of the flight path relative to magnetic North with North as 0 or 360 degrees, East as 90, South as 180, and West as 270 degrees. For example, the X coordinates for an idealized flight line in the direction of 180 degrees (South) would be increasingly positive to the left of the flight line and increasingly negative to the right of the flight line with the X coordinate for the nadir pixel being approximately 0 (zero).

Relative Y Coordinate

The Y coordinate of the center of the image pixel in relation to the arbitrarily selected origin. The trend of the Y coordinates of the pixels is dependent on the direction of flight of the aircraft. The X, Y coordinate system, starts with the nadir pixel location of image line 1 for all flight lines positioned near the origin (0,0) and progresses based on the direction of flight. The flight direction refers to the angle of the flight path relative to magnetic North with North as 0 or 360 degrees, East as 90, South as 180, and West as 270 degrees. For example, the Y coordinates for an idealized flight line in the direction of 90 degrees (East) would be increasingly positive to the left of the flight line and increasingly negative to the right of the flight line with the Y coordinate for the nadir pixel being approximately 0 (zero).

Scaled View Zenith

The scaled value of the target-centered view zenith angle (complement of elevation angle). The view zenith indicates the zenith angle at which the radiant energy was traveling when detected by the sensor. The view zenith angle increases from 0 (straight up) to 90 degrees at the horizon.

Scaled View Azimuth

The scaled value of the target-centered view azimuth angle. The view azimuth angle indicates the direction in which the radiant energy was traveling when detected by the sensor. The view azimuth angle increases from 0 to 360 degrees with North as 0 or 360 degrees, East as 90, South as 180, and West as 270 degrees.

The descriptions of the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Description
SPATIAL_COVERAGE	The general term used to denote the spatial area over which the data were collected.
DATE_OBS	The date on which the data were collected.
START_TIME	The starting Greenwich Mean Time (GMT) for the data collected.
END_TIME	The ending Greenwich Mean Time (GMT) for the data collected.
PLATFORM	The object (e.g., satellite, aircraft, tower, person) that supported the instrument.
INSTRUMENT	The name of the device used to make the measurements.
NUM_BANDS	The number of spectral bands in the data.
PLATFORM_ALTITUDE	The nominal altitude of the data collection platform above the target.
MIN_SOLAR_ZEN_ANG	The minimum angle from the surface normal (straight up) to the sun during the data collection.
MAX_SOLAR_ZEN_ANG	The maximum angle from the surface normal (straight up) to the sun during the data collection.
MIN_SOLAR_AZ_ANG	The minimum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
MAX_SOLAR_AZ_ANG	The maximum azimuthal direction of the sun during data collection expressed in clockwise increments from North.
C130_MISSION_ID	The mission identifier assigned to the C-130 mission in the form of YY-DDD-FF where YY is the last two digits of the fiscal year, DDD is the deployment number for "official" C-130 missions and is day of year for non-"official" C-130 missions (i.e., no site coverage), and FF is the flight number within the given deployment (00 is given for non-"official" C-130 missions). An example would be 94-006-04.
C130_LINE_NUM	The number of the C-130 line in its flights over the BOREAS area as given in the flight logs. Zero values are given for non-"official" C-130 missions and for data between C-130 sites or lines.
C130_RUN_NUM	The number of the C-130 run in its flights over the BOREAS area as given in the flight logs. Zero value is given for non-"official" C-130 missions and data between C-130 sites, lines or runs.
C130_SITE	The C-130 site designator as given in the flight logs. PRE is used for data taken from the airport to the first "official" C-130 site, BTW is used for data taken between two "official" C-130 sites, DSC is used for data taken after the last

	"official" C-130 site, TRN is used for transect data, and YTH and YPA are used for data taken at the YTH and YPA airports (aircraft never left the ground).
BAND_QUALITY	The data analyst's assessment of the quality of the spectral bands in the data.
CLOUD_COVER	The data analyst's assessment of the cloud cover that exists in the data.
MAS_SCAN_SPEED	The rate of scan line data collection by the MAS instrument during the given flight.
NW_LATITUDE	The NAD83 based latitude coordinate of the north-west corner of the minimum bounding rectangle for the data.
NW_LONGITUDE	The NAD83 based longitude coordinate of the northwest corner of the minimum bounding rectangle for the data.
NE_LATITUDE	The NAD83 based latitude coordinate of the north east corner of the minimum bounding rectangle for the data.
NE_LONGITUDE	The NAD83 based longitude coordinate of the north east corner of the minimum bounding rectangle for the data.
SW_LATITUDE	The NAD83 based latitude coordinate of the south west corner of the minimum bounding rectangle for the data.
SW_LONGITUDE	The NAD83 based longitude coordinate of the southwest corner of the minimum bounding rectangle for the data.
SE_LATITUDE	The NAD83 based latitude coordinate of the south east corner of the minimum bounding rectangle for the data.
SE_LONGITUDE	The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).

7.3.3 Unit of Measurement

For the image data files:

```
Scaled At-sensor radiance - Fractions of Watts/(square meter * steradian *
                            micrometer).  Look near the end of the ASCII header
                            file for scaling factors.
Relative X coordinate - meters
Relative Y coordinate - meters
Scaled View zenith - Tenths of degrees
Scaled View Azimuth - Tenths of degrees
```

The measurement units for the parameters contained in the inventory listing file on the CD-ROM are:

Column Name	Units
SPATIAL_COVERAGE	[none]
DATE_OBS	[DD-MON-YY]
START_TIME	[HHMM GMT]
END_TIME	[HHMM GMT]
PLATFORM	[none]
INSTRUMENT	[none]
NUM_BANDS	[counts]
PLATFORM_ALTITUDE	[meters]
MIN_SOLAR_ZEN_ANG	[degrees]
MAX_SOLAR_ZEN_ANG	[degrees]
MIN_SOLAR_AZ_ANG	[degrees]
MAX_SOLAR_AZ_ANG	[degrees]
C130_MISSION_ID	[none]
C130_LINE_NUM	[none]
C130_RUN_NUM	[none]
C130_SITE	[none]
BAND_QUALITY	[none]
CLOUD_COVER	[none]
MAS_SCAN_SPEED	[scan lines][second^-1]
NW_LATITUDE	[degrees]
NW_LONGITUDE	[degrees]
NE_LATITUDE	[degrees]
NE_LONGITUDE	[degrees]
SW_LATITUDE	[degrees]
SW_LONGITUDE	[degrees]
SE_LATITUDE	[degrees]
SE_LONGITUDE	[degrees]
CRTFCN_CODE	[none]

7.3.4 Data Source

The values stored in the listed parameters were extracted from the level-1b MAS HDF files provided to BOREAS by MAS processing personnel. The scaled at-sensor radiance and view angle values are the result of calibration and processing of the raw MAS data by MAS personnel. The relative X and Y coordinates were derived in a joint effort between BORIS and MAS personnel using developed software. The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

Column Name	Data Source
SPATIAL_COVERAGE	[Determined from latitude and longitude information provided in the NASA Ames flight summary reports and navigation data files]
DATE_OBS	[Software extracted from MAS HDF files]
START_TIME	[Software extracted from MAS HDF files]
END_TIME	[Software extracted from MAS HDF files]
PLATFORM	[Data base constant]
INSTRUMENT	[Data base constant]
NUM_BANDS	[Data base constant]
PLATFORM_ALTITUDE	[Determined from information provided in the NASA Ames flight summary reports]

MIN_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_ZEN_ANG	[Calculated with software from latitude and longitude and time information]
MIN_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
MAX_SOLAR_AZ_ANG	[Calculated with software from latitude and longitude and time information]
C130_MISSION_ID	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
C130_LINE_NUM	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
C130_RUN_NUM	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
C130_SITE	[Taken from the delivered tape label and the NASA Ames Flight Summary Reports]
BAND_QUALITY	[Constant software parameter value]
CLOUD_COVER	[Constant software parameter value]
MAS_SCAN_SPEED	[Software extracted from MAS HDF files]
NW_LATITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
NW_LONGITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
NE_LATITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
NE_LONGITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
SW_LATITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
SW_LONGITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
SE_LATITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
SE_LONGITUDE	[Calculated with software from the C-130 altitude and heading, starting and ending flight line latitude and longitude, and the static MAS scan angle information]
CRTFCN_CODE	[Constant data base value]

7.3.5 Data Range

The range of values for the image data files are:

Scaled At-sensor Radiance

Dependent on the particular MAS band of interest due to the wavelength region covered and the scaling factor listed near the end of the ASCII header file.

Relative X Coordinate

Dependent on the direction of flight with an absolute minimum of -2,147,483,648 and absolute maximum of 2,147,483,647.

Relative Y Coordinate

Dependent on the direction of flight with an absolute minimum of -2,147,483,648 and absolute maximum of 2,147,483,647.

Scaled View Zenith

Minimum - 0
Maximum - 900

Scaled View Azimuth

Minimum - 0
Maximum - 3599

The following table gives information about the parameter values found in the inventory table on the CD-ROM.

Column Name	Minimum Data Value	Maximum Data Value	Missng Data Value	Unrel Data Value	Below Detect Limit	Data Not Cllctd
SPATIAL_COVERAGE	N/A	N/A	None	None	None	None
DATE_OBS	21-JUL-94	08-AUG-94	None	None	None	None
START_TIME	1431	2110	None	None	None	None
END_TIME	1435	2115	None	None	None	None
PLATFORM	C-130	C-130	None	None	None	None
INSTRUMENT	N/A	N/A	None	None	None	None
NUM_BANDS	12	12	None	None	None	None
PLATFORM_ALTITUDE	5369	7962	None	None	None	None
MIN_SOLAR_ZEN_ANG	33.5	60.8	None	None	None	None
MAX_SOLAR_ZEN_ANG	33.5	60.8	None	None	None	None
MIN_SOLAR_AZ_ANG	104.7	228.4	None	None	None	None
MAX_SOLAR_AZ_ANG	104.7	228.4	None	None	None	None
C130_MISSION_ID	94-007-02	94-007-07	None	None	None	None
C130_LINE_NUM	1	703	None	None	None	None
C130_RUN_NUM	1	2	None	None	None	None
C130_SITE	429	432	None	None	None	None
BAND_QUALITY	N/A	N/A	None	None	None	None
CLOUD_COVER	N/A	N/A	None	None	None	None
MAS_SCAN_SPEED	6.25	6.25	None	None	None	None
NW_LATITUDE	53.67695	56.08457	None	None	None	None
NW_LONGITUDE	-106.49118	-98.43622	None	None	None	None
NE_LATITUDE	53.65457	56.02245	None	None	None	None
NE_LONGITUDE	-106.04228	-98.01404	None	None	None	None
SW_LATITUDE	53.45052	55.92475	None	None	None	None
SW_LONGITUDE	-106.50745	-98.48084	None	None	None	None

```
SE_LATITUDE          53.44061       55.88116       None     None    None     None
SE_LONGITUDE         -106.06016     -98.06009      None     None    None     None
CRTFCN_CODE          CPI-PRE        CPI-PRE        None     None    None     None
--------------------------------------------------------------------------------
Minimum Data Value -- The minimum value found in the column.
Maximum Data Value -- The maximum value found in the column.
Missng Data Value  -- The value that indicates missing data. This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the attempt was unsuccessful.
Unrel Data Value   -- The value that indicates unreliable data.  This is used
                      to indicate an attempt was made to determine the
                      parameter value, but the value was deemed to be
                      unreliable by the analysis personnel.
Below Detect Limit -- The value that indicates parameter values below the
                      instruments detection limits.  This is used to
                      indicate that an attempt was made to determine the
                      parameter value, but the analysis personnel determined
                      that the parameter value was below the detection
                      limit of the instrumentation.
Data Not Cllctd    -- This value indicates that no attempt was made to
                      determine the parameter value.  This usually
                      indicates that BORIS combined several similar but
                      not identical data sets into the same data base table
                      but this particular science team did not
                      measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A   -- Indicates that the value is not applicable to the respective column.
None  -- Indicates that no values of that sort were found in the column.
--------------------------------------------------------------------------------
```

7.4 Sample Data Record

A sample data record for the level-1b MAS image data files is not available here. The following are wrapped versions of the first few records from the level-1b MAS inventory table on the CD-ROM:

```
SPATIAL_COVERAGE,DATE_OBS,START_TIME,END_TIME,PLATFORM,INSTRUMENT,NUM_BANDS,
PLATFORM_ALTITUDE,MIN_SOLAR_ZEN_ANG,MAX_SOLAR_ZEN_ANG,MIN_SOLAR_AZ_ANG,
MAX_SOLAR_AZ_ANG,C130_MISSION_ID,C130_LINE_NUM,C130_RUN_NUM,C130_SITE,
BAND_QUALITY,CLOUD_COVER,MAS_SCAN_SPEED,NW_LATITUDE,NW_LONGITUDE,NE_LATITUDE,
NE_LONGITUDE,SW_LATITUDE,SW_LONGITUDE,SE_LATITUDE,SE_LONGITUDE,CRTFCN_CODE
'SSA',21-JUL-94,1546,1549,'C130','MAS',12,7962.0,50.1,50.1,111.9,111.9,
'94-007-02',1,1,'430','Fair: some noise in IR channels','NOT ASSESSED',
6.25,54.09045,-104.73796,54.06945,-104.35302,53.94723,-104.7599,53.9263,
-104.3763,'CPI-PRE'
'SSA',21-JUL-94,1555,1600,'C130','MAS',12,7847.0,48.7,48.7,114.7,114.7,
'94-007-02',2,1,'430','Fair: some noise in IR channels','NOT ASSESSED',
6.25,54.1104,-104.95096,54.07979,-104.37902,53.91345,-104.98007,53.88298,
-104.41086,'CPI-PRE'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for level-1b MAS images is a single image - one of the 16 image bands of a MAS scene collected over the BOREAS SSA and NSA. Each scene represents imaging performed over a portion of a sight during one flight line. A scene is made up of 17 sequential 8-mm tape files described below.

8.2 Data Format(s)

The CD-ROM inventory listing file consists of numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

One level-1b MAS image product consists of 17 files in the following order:

```
File 1: An ASCII header file that containing information relating to the
      mission, location, acquisition time, sensor parameters, aircraft
      location and attitude, and radiometric calibration parameters.
Files 2 - 13: Bands 1 to 12 stored as 16-bit binary values in fractions of
      Watts/(square meter * steradian * micrometer)
      (low order byte first). Look near the end of the ASCII header
      file for scaling factors
File 14: Relative X coordinates stored as 32-bit binary values in tenths of
      meters. (low order byte first).
File 15: Relative Y coordinates stored as 32-bit binary values in tenths of
      meters. (low order byte first).
File 16: Scaled view zenith values stored as 16-bit binary values in tenths of
      degrees. (low order byte first).
File 17: Scaled view azimuth values stored as 16-bit binary values in tenths of
      degrees. (low order byte first).
```

The second scene on the tape occupies tape files 18 - 34. The third scene on the tape occupies tape files 35 - 47 and so on.

The geographic orientation of each scene depends on the direction of the aircraft line of flight. Pixels and lines progress left to right, and top to bottom so that pixel n, line n is in the lower right-hand corner of each scene.

All scene files exist on tape as a variable number of fixed length records. ASCII header files are 80 bytes in length. All binary files associated together for a given flight contain the same number of records. The number of binary records in a flight varies depending on the length of that flight line. Each binary data record in all flights represents 716 image pixels and are padded to an even multiple of 512. Therefore, the image and view angle file records contain 716*2 + 104 bytes of padding = 1536 bytes and the relative X and Y coordinate files contain 716*4 + 208 bytes of padding = 3072 bytes.

9. Data Manipulations

9.1 Formulae

9.1.1 Derivation Techniques and Algorithms

Derivation of the relative X and Y coordinates starts with determining the relative positions of the nadir pixel in each image line. The nadir pixel coordinates are defined to proceed relative to an arbitrary starting X,Y location. Nadir X,Y coordinates are derived as a function of the following parameters:

- Instantaneous Velocities X, Y, and Z from the C-130 navigation data.
- Tracking (actual direction aircraft is pointing) values derived as a function of true heading and drift. To arrive upon nadir pixel tracking, the 1-Hz drift values and 30-Hz true heading values are interpolated to nadir pixel values. Nadir pixel drift is added to the nadir true heading values to obtain nadir pixel tracking values. Note that drift may be a positive or negative value.

The calculations used to derive relative X and Y coordinates of the nadir pixels are:

```
X0       = First (earlier) nadir X location
X1       = Succeeding nadir X location
Y0       = First (earlier) nadir Y location
Y1       = Succeeding nadir Y location
DTime    = Time1 - Time0
           [Delta time stamps between succeeding nadir pixels]
TH0, TH1 = True Heading at succeeding nadir pixels
Dr0, Dr1 = Drift values at succeeding nadir pixels
Tr0, Tr1 = Tracking at succeeding nadir pixels
VX,VY,VZ = GPS velocities in an X, Y and Z GPS reference system
Sp0, Sp1 = Ground Speed
           [square root ((VX*VX) + (VY*VY) + (VZ*VZ))]
V0x      = SP0 * cos(TH0 + Dr0)
           [X Velocity at Time0]
V1x      = SP1 * cos(TH1 + Dr1)
           [X Velocity at Time1]
V0y      = SP1 * sin(TH0 + Dr0)
           [Y Velocity at Time0]
V1y      = SP1 * sin(TH1 + Dr1)
           [Y Velocity at Time1]
AVEV01X  = (V0x + V1x) / 2.0
           [Average X velocity between Time0 and Time1]
AVEV01Y  = (V0y + V1y) / 2.0
           [Average Y velocity between Time0 and Time1]
X        = X0 + (AVE01X * DTime)
           [Succeeding nadir X coordinate]
Y        = Y0 + (AVE01Y * Dtime)
           [Succeeding nadir Y coordinate]
```

Once the position of the aircraft at the center pixel time is known, what remains to be determined is the center pixel position on the ground and along the scan line on each side. The latter is determined by dividing the ScanAngle by the number or pixels, e.g.:

```
if (pixel <= 0  )
             ScanAngle = - fabs(AngleIncr * (pixel));
          else
             ScanAngle =  fabs(AngleIncr * (pixel));
```

The Center Pixel Position on the ground is determined by the trigonometry of the sensor's position which varies by pitch, altitude, heading and scan angle as the MAS sensor is roll-compensated:

```
XCoords[pixel] = x0 + alt*tan(pitch)*sin(head) -
                 alt/cos(pitch) * (tan(ScanAngle)) * cos(head);

YCoords[pixel] = y0 + alt*tan(pitch)*cos(head) +
                 alt/cos(pitch) * (tan(ScanAngle)) * sin(head);
```

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff creates the level-1b MAS image products from HDF files. The input HDF file is created by combining MAS image data with aircraft navigation data in an iterative procedure as follows:

- BORIS staff extracts start and end flight line times from the level-0 C-130 aircraft navigation data associated with the flight.
- The start and end times for the flight line are used by BORIS staff to extract the relevant aircraft navigation data to determine nadir pixel times.
- BORIS staff processes/linearly interpolates the extracted navigation parameters such as roll, pitch, heading, drift, and acceleration for the nadir pixel time.
- The nadir location parameters (roll, pitch, radar altitude, X and Y grid coordinates) are plotted to perform visual review of the data for anomalous values.
- Nadir pixel navigation parameter values are then combined with MAS spectral data by MAS processing staff to create an HDF image product consisting of MAS spectral data and ancillary information for each flight line run.
- All HDF files are written to 8-mm tape and logged in the BORIS data base.
- Each MAS HDF file is converted to the BORIS BSQ 8-mm tape product.
- The 17 files, as described above, for each unique flight, are written to tape, in BORIS level-1b BSQ format, for distribution.
- The BORIS format MAS tapes are then logged into the BORIS data base.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

See Section 9.1.1.

9.3.2 Calculated Variables

See Section 9.1.1.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

Errors could arise in the acquired imagery due to location accuracy, distortion of lengths, anisomorphism, instrument's local coherence, and multispectral registerability. Other errors could arise from inherent radiometric imperfections of the sensors.

Whatever the processing level, the geometric quality of the image depends on the accuracy of the viewing geometry.

Spectral errors could arise due to image-wide signal-to-noise ratio, saturation, cross-talk, spikes, and response normalization due to change in gain.

10.2 Quality Assessment

10.2.1 Data Validation by Source

None.

10.2.2 Confidence Level/Accuracy Judgment

One set of calibration coefficients was used throughout the BOREAS project rather than recalculating for each flight. Errors are usually +/- 5% when recalculated for each flight.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

None.

10.2.5 Data Verification by Data Center

BORIS staff calculated the length of the sides of the images from the X and Y coordinate files of the MAS scenes and compared with data from the flight summary report: An image with 1,416 scan lines at 6.25 scan/sec should have a flight time of 226 secs. A flight time of 226 secs at 200 knots should yield an image that is 23 km long. An instrument with a TFOV of 85.92° at an altitude of 8,000 m should produce an image with a ground width of 7.5 km.

BORIS staff visually compared some of the MAS images that were geometrically (not geographically) corrected with the relative X and Y coordinates to registered Landsat Thematic Mapper (TM) images. The geometry and positioning of the features in the MAS images matched well with those in the Landsat TM scene.

11. Notes

11.1 Limitations of the Data

None.

11.2 Known Problems with the Data

None.

11.3 Usage Guidance

None.

11.4 Other Relevant Information

None.

12. Application of the Data Set

These data could be used as a first step to creating surface energy and reflectance maps of the imaged areas. They could also be used in comparison studies with the Landsat images acquired over the areas. Lastly, they could be compared with actual MODIS data after it is available later in 1999.

13. Future Modifications and Plans

None given.

14. Software

14.1 Software Description

BORIS personnel developed software and command procedures to:

- Unpack and subset the level-0 C-130 navigation data.
- Perform linear interpolation of the level-0 C-130 navigation parameters.
- Convert the HDF data files received from MAS personnel to the BORIS BSQ 8-mm tape product.
- Write the 17 files for each unique flight to tape for distribution.
- Extract header information from level-1b BSQ images on tape.
- Log the BSQ format MAS tapes into the BORIS data base.

The software is written in the C language and is operational on VAX 6410 and MicroVAX 3100 systems at GSFC. The primary dependencies in the software are the tape I/O library and the Oracle data base utility routines.

The details of the software used by MAS personnel to derive the HDF level-1b products are currently unknown.

14.2 Software Access

All of the described BORIS software is available upon request. BORIS staff would appreciate knowing of any problems discovered with the software, but cannot promise to fix them.

15. Data Access

The level-1b MAS images are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

The BOREAS level-1b MAS data can be made available on 8-mm, Digital Archive Tape (DAT), or 9-track tapes at 1600 or 6250 Bytes Per Inch (BPI).

16.2 Film Products

Color aerial photographs and video records were made during data collection. The video record includes aircraft crew cabin intercom conversations and an audible tone that was initiated each time the sensor was triggered. The BOREAS data base contains an inventory of available BOREAS aircraft flight documentation, such as flight logs, video tapes, and photographs.

16.3 Other Products

Although the inventory is contained on the BOREAS CD-ROM set, the actual level-1b MAS images are not. See Section 15 for information about how to obtain the data.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

Arnold, G.T., M. Fitzgerald, P.S. Grant, and M.D. King. 1994a. MODIS Airborne Simulator Visible and Near-Infrared Calibration - 1992 ASTEX Field Experiment: Calibration Version - ASTEX King 1.0. NASA Technical Memorandum 104599, 19 pp.

Arnold, G.T., M. Fitzgerald, P.S. Grant, and M.D. King. 1994b. MODIS Airborne Simulator Visible and Near-Infrared Calibration - 1991 FIRE-Cirrus Field Experiment: Calibration Version - FIRE King 1.1. NASA Technical Memorandum 104600, 23 pp.

Gumley, L.E., P.A. Hubanks, and E.J. Masuoka. 1994. MODIS Airborne Simulator Level 1B data user's guide. NASA Technical Memorandum 104594 Vol. 3, NASA Goddard Space Flight Center, Greenbelt MD.

17.2 Journal Articles and Study Reports

Anderson, G.P. and J.H. Chetwynd. 1992. FASCOD3P User's Guide, Phillips Laboratory, Hanscom AFB.

Ardanuy, P.E., D. Han, and V.V. Salomonson. 1991. The Moderate Resolution Imaging Spectrometer (MODIS) science and data system requirements. IEEE Trans. Geosci. Remote Sens., 29, 75-88.

Bromba, M.U.A. and H. Ziegler. 1981. Digital filter for computationally efficient smoothing of noisy spectra. Anal. Chem., 53, 1299-1302.

Clough, S.A., F.X. Kneizys, L.S. Rothman, and W.O. Gallery. 1981. Atmospheric spectral transmittance and radiance: FASCOD1B. SPIE, 277, 152-166.

Gao, B.C., A.F.H. Goetz, and W.J. Wiscombe. 1993. Cirrus cloud detection from airborne imaging spectrometer data using the 1.38 mm water vapor band. Geophys. Res. Lett., 20, 301-304.

Gumley, L.E. and M.D. King. 1995. Remote sensing of flooding in the US upper Midwest during the summer of 1993. Bull. Amer. Meteor. Soc., 76, 933-943.

Huh, O.K., C.C. Moeller, W.P. Menzel, L.J. Rouse, Jr., and H.H. Roberts. 1995. Remote sensing of turbid coastal and estuarine water: A method of multispectral water-type analysis. Submitted to J. Coastal Res.

Jedlovec, G.J., K.B. Batson, R.J. Atkinson, C.C. Moeller, W.P. Menzel, and M.W. James. 1989. Improved Capabilities of the Multispectral Atmospheric Mapping Sensor (MAMS). NASA Technical Memorandum 100352, Marshall Space Flight Center, Huntsville, AL, 71 pp.

Kaufman, Y.J. and B.C. Gao. 1992. Remote sensing of water vapor in the near IR from EOS/MODIS. IEEE Trans. Geosci. Remote Sens., 30, 871-884.

King, M.D., D.D. Herring, and D.J. Diner. 1995. The Earth Observing System (EOS): A space-based program for assessing mankind's impact on the global environment. Opt. Photon. News, 6, 34-39.

King, M.D., W.P. Menzel, P.S. Grant, J.S. Meyers, G.T. Arnold, S.E. Platnick, L.E. Gumley, S. Tsay, C.C. Moeller, M. Fitzgerald, K.S. Brown, and F.G. Osterwisch. 1995. Airborne Scanning Spectrometer for Remote Sensing of Cloud, Aerosol, Water Vapor and Surface Properties. Journal of Atmospheric and Oceanic Technology.

King, M.D., Y.J. Kaufman, W.P. Menzel, and D. Tanre. 1992. Remote sensing of cloud, aerosol, and water vapor properties from the Moderate Resolution Imaging Spectrometer (MODIS). IEEE Trans. Geosci. Remote Sens., 30, 2-27.

Moeller, C.C., O.K. Huh, H.H. Roberts, L.E. Gumley, and W.P. Menzel. 1993. Response of Louisiana coastal environments to a cold front passage. J. Coastal Res. 9, 434-447.

Nakajima, T. and M.D. King. 1990. Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements. Part I: Theory. J. Atmos. Sci., 47, 1878-1893.

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. 2000. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM.

Revercomb, H.E., H. Buijs, H.B. Howell, D.D. LaPorte, W.L. Smith, and L.A. Sromovsky. 1988. Radiometric calibration of IR Fourier transform spectrometers: Solution to a problem with the High-spectral resolution Interferometer Sounder. Appl. Opt., 27, 3210-3218.

Running, S.W., C.O. Justice, V. Salomonson, D. Hall, J. Barker, Y.J. Kaufman, A.H. Strahler, A.R. Huete, J.P. Muller, V. Vanderbilt, Z.M. Wan, P. Teillet, and D. Carneggie. 1994. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. Int. J. Remote Sens., 15, 3587-3620.

Sellers, P. and F. Hall. 1994. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1994-3.0, NASA BOREAS Report (EXPLAN 94).

Sellers, P. and F. Hall. 1996. Boreal Ecosystem-Atmosphere Study: Experiment Plan. Version 1996-2.0, NASA BOREAS Report (EXPLAN 96).

Sellers, P., F. Hall, and K.F. Huemmrich. 1996. Boreal Ecosystem-Atmosphere Study: 1994 Operations. NASA BOREAS Report (OPS DOC 94).

Sellers, P., F. Hall, and K.F. Huemmrich. 1997. Boreal Ecosystem-Atmosphere Study: 1996 Operations. NASA BOREAS Report (OPS DOC 96).

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. den Hartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. 76(9):1549-1577.

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment Overview, Scientific Results and Future Directions. Journal of Geophysical Research 102(D24): 28,731-28,770.

Smith, W.L., R.O. Knuteson, H.E. Revercomb, W. Feltz, H.B. Howell, W.P. Menzel, N. Nalli, O. Brown, J. Brown, P. Minnett, and W. McKeown. 1995. Observations of the infrared radiative properties of the ocean - Implications for the measurement of sea surface temperature via satellite remote sensing. Submitted to Bull. Amer. Meteor. Soc.

Strabala, K.I., S.A. Ackerman, and W.P. Menzel. 1994. Cloud properties inferred from 8-12 mm data. J. Appl. Meteor., 33, 212-229.

Tsay, S.C., K. Stamnes, and K. Jayaweera. 1989. Radiative energy balance in the cloudy and hazy Arctic. J. Atmos. Sci., 46, 1002-1018.

Tsay, S.C., K. Stamnes, and K. Jayaweera. 1990. Radiative transfer in planetary atmospheres: Development and verification of a unified model. J. Quant. Spectrosc. Radiat. Transfer, 43, 133-148.

Twomey, S. and T. Cocks. 1982. Spectral reflectance of clouds in the near-infrared: Comparison of measurements and calculations. J. Meteor. Soc. Japan, 60, 583-592.

Wylie, D.P., W.P. Menzel, H.M. Woolf, and K.I. Strabala. 1994. Four years of global cirrus cloud statistics using HIRS. J. Clim., 7, 1972-1986.

17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

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ARC      - Ames Research Center
ASCII    - American Standard Code for Information Interchange
BOREAS   - BOReal Ecosystem-Atmosphere Study
BORIS    - BOREAS Information System
BPI      - Bytes Per Inch
BSQ      - Band Sequential
CCT      - Computer Compatible Tape
CD-ROM   - Compact Disk-Read-Only Memory
DAAC     - Distributed Active Archive Center
DAT      - Digital Archive Tape
EOS      - Earth Observing System
EOSDIS   - EOS Data and Information System
FIRE     - First ISCCP Regional Experiment
FOV      - Field-of-View
fPAR     - fraction of Photosynthetically Active Radiation
GIS      - Geographic Information System
GMT      - Greenwich Mean Time
GPS      - Global Positioning System
GSFC     - Goddard Space Flight Center
HDF      - Hierarchical Data Format
IFC      - Intensive Field Campaign
IFOV     - Instantaneous Field-of-View
IR       - Infrared
ISCCP    - International Satellite Cloud Climatology Project
LAI      - Leaf Area Index
MAS      - MODIS Airborne Simulator
MODIS    - MODerate Imaging Spectroradiometer
MODLAND  - MODIS Land Group
NAD83    - North American Datum of 1983
NASA     - National Aeronautics and Space Administration
NIR      - Near-Infrared
NSA      - Northern Study Area
OA       - Old Aspen
OBS      - Old Black Spruce
OJP      - Old Jack Pine
ORNL     - Oak Ridge National Laboratory
PANP     - Prince Albert National Park
SSA      - Southern Study Area
TM       - Thematic Mapper
URL      - Uniform Resource Locator
YA       - Young Aspen
YJP      - Young Jack Pine
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20. Document Information

20.1 Document Revision Date
Written: 25-Apr-1995
Last Updated: 06-Jul-1999

20.2 Document Review Date
BORIS Review: 09-Jun-1998
Science Review:

20.3 Document ID

20.4 Citation
When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:

The level-1b MAS images were derived in a joint effort by both BORIS and MAS personnel at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). The contributions of the above individuals and agencies to completing this data set are greatly appreciated.

Also, cite the BOREAS CD-ROM set as:

Newcomer, J., D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers, eds. Collected Data of The Boreal Ecosystem-Atmosphere Study. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 2000

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)
BOREAS Level-1B MAS Imagery: At-sensor Radiance, Relative X and Y Coordinates

5. FUNDING NUMBERS
923
RTOP: 923-462-33-01

6. AUTHOR(S)
Richard Strub, Paul Hubanks, Jeffrey A. Newcomer, and Stephan Ungar
Forrest G. Hall, Editor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES)
Goddard Space Flight Center
Greenbelt, Maryland 20771

8. PEFORMING ORGANIZATION REPORT NUMBER
2000-03136-0

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
TM—2000–209891
Vol. 87

11. SUPPLEMENTARY NOTES
R. Strub and J. A. Newcomer: Raytheon ITSS; P. Hubanks: RDC

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category: 43
Report available from the NASA Center for AeroSpace Information,
7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

For BOREAS, the MAS images, along with the other remotely sensed data, were collected to provide spatially extensive information over the primary study areas. This information includes detailed land cover and biophysical parameter maps such as fPAR and LAI. Collection of the MAS images occurred over the study areas during the 1994 field campaigns. The level-1b MAS data cover the dates of 21-Jul-1994, 24-Jul-1994, 04-Aug-1994, and 08-Aug-1994. The data are not geographically/geometrically corrected; however, files of relative X and Y coordinates for each image pixel were derived by using the C-130 INS data in a MAS scan model. The data are provided in binary image format files.

14. SUBJECT TERMS
BOREAS, remote sensing science, MAS images.

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL